[INTRODUCTION]

Grand Challenges for physics

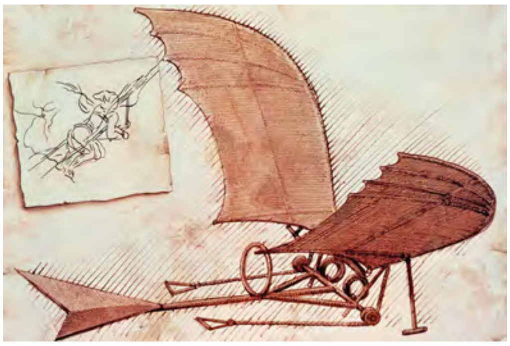
Our developed society is based on science and technology but only a minority of the general public has an understanding of how they work. Equally unknown are the opportunities opened by fundamental research and their impact in our daily lives.

The history of science offers a wide range of examples of discoveries with unforeseen social value. The discovery of the delicate mechanism by which ozone is naturally produced and destroyed in the stratosphere is a good example. It illustrates how vulnerable the Earth actually is under human stewardship, while at the same time illustrates the human capability to address challenges making use of basic science with a mixture of scientific curiosity and a touch of environmental awareness. Scientific endeavour means very often exploring unknown territories. Here its strength lies in its capability for developing self-correcting strategies based on available evidence to explore the limits of science and the science of limits.

Historically scientific breakthroughs have been steady but slow, occurring over a span of centuries. Leonardo da Vinci [1452-1519] was a true Renaissance person. His artistic talent is comparable to his genius to dream the future. Leonardo da Vinci's greatest ambition was to fly. Centuries later, flying like a bird was still a dream in Goya´s time [1746 – 1828]. Fly has been a driver of creativity and fantasy - to go where no one has gone before, to overcome human limits, to fulfil high and demanding goals. It took more than 500 years to build a flying machine that would allow humans to get a unique view of our planet. A photograph, snapped from the Voyager 1 in 1990 at a distance of about 6 thousand million kilometres, showed our planet as a lonely pale blue dot in the great enveloping cosmic dark. A unique image taken by scientists that exceeded Leonardo's and Goya dreams a few centuries latter.

Today the pace of innovation has accelerated drastically. Over the last decades, the European Physical Society community has been promoting and examining some of the biggest problems humankind faces right now and the role physics to address them. But what about the big challenges in physics that are brewing for the future?. In the Horizon 2050, what challenges might be on the world's physics agenda to solve? Predictions are difficult to be made but we can get clues from how current trends in science and technology may play

▾ Leonardo Da Vinci's first attempt to fly was in the late 15th century. He never succeeded to make his dream reality.



▲ In one of Goya´s most striking prints, a series of people are flying through an endless night (Goya, El Prado Museum). They are like new Icaruses, assisted by broad wings. The story of Icarus is one of the most famous tales from Greek myth that is often interpreted as a metaphor for human's overreaching their limits.

out, and where physics has a key role to play. This is the purpose of the *EPS Grand Challenges: Physics for Society at the Horizon 2050 project*, exploring our ability to imagine and shape the future using modern day scientific tools and methods. The project is designed to address the social dimension of science and the grand challenges in physics with two pillars: (i) *physics as global human enterprise for understanding nature*; and (ii) *physics developments to tackling major issues affecting the lives of citizens*. A fascinating journey, from the smallest scale that we have ever explored – quarks particles that are of the scale of 10^{-18} m – to the largest things we have ever mesured – the greater breadth of the universe at the scale of 10^{27} m. A project highlighting the key role of interdisciplinarity to address some of the grand scientific and social challenges that lay ahead us, such as the climate change or understanding life.

An editiorial board and chapter coordinators from different European institutions played a key role in the development of the project and the preparation of a book. More than ten Editorial Board meetings were held during 2019 – 2021 to approve terms of reference and topics to be covered in seven chapters of the book: (i) Physics bridging the infinities; (ii) Matter and waves; (iii) Physics for understanding life; (iv) Physics for health; (v) Physics for environment and sustainable development; (vi) Physics for secure and efficient societies; (vii) Science for society.

All these topics are widely recognised today as the most important global challenges in physics. Interdisciplinarity allows interconnections between many areas of knowledge, involving physics, mathematics, biology and chemistry, in such a way that the whole body of connected ideas might suddenly expand due to small advances within the islands of specialised knowledge. In the project, we have looked at all these aspects to explore what makes us, human beings, really unique in nature: our ability to shape the future by making use of science and technology.

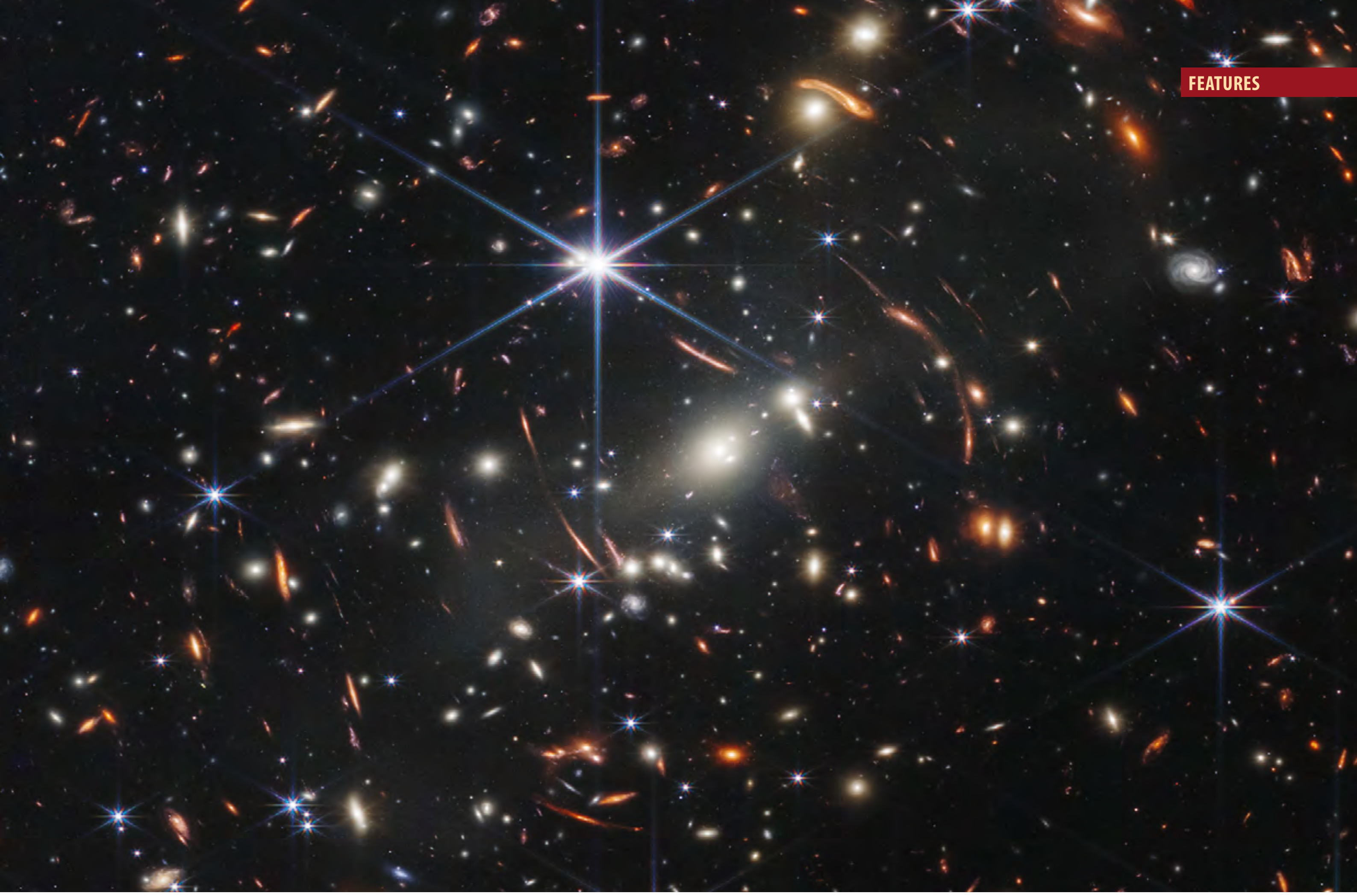
This EPN special issue provides a glimpse of the *EPS Grand Challenges in the Horizon 2050 project* addressing world's physics agenda to solve in science and technology. The resulting book will be published by IOPP under the umbrella of the EPS in early 2023. The most up to date information will be published here: https://www.eps.org/page/GrandChallengesInPhysics.

The essays, prepared by a panel of more than 70 leading scientists, are based on detailed and in-depth analyses to illustrate the strong links between basic research and its social impact. Reports are expected to reach a broad audience that is willing to explore a future shaped by science. ■

■ **Carlos Hidalgo**
Laboratorio Nacional de Fusión,
CIEMAT, Madrid, Spain
■ **David Lee,**
EPS General Secretary

THANK YOU!

The EPN Editors are very grateful to Carlos Hidalgo, who as Guest Editor introduced us to the 'EPS Grand Challenges for Physics' project. Together with the many coordinators of the project and with an excellent introduction together with David Lee, an attractive overview is given of the many chapters in the project, that will be published as a book by IoP. We highly appreciate your work and endeavour for EPN. Thanks a lot to all of you!



PHYSICS
BRIDGING THE INFINITIES

Mairi Sakellariadou[1] **and Claudia-Elisabeth Wulz**[2] – DOI: https://doi.org/10.1051/epn/2021502

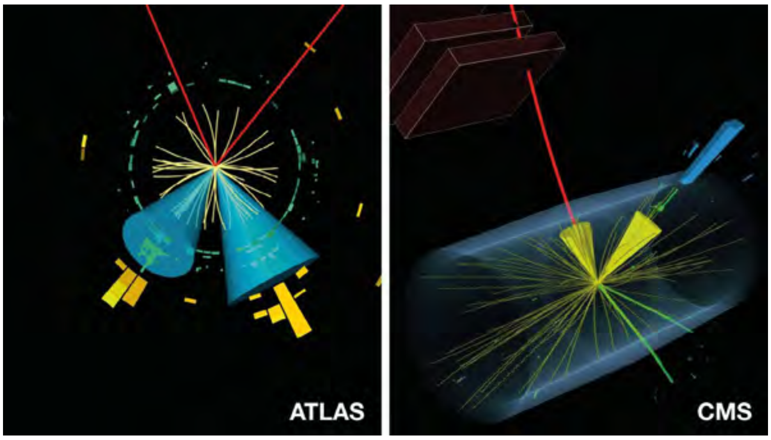
[1] King's College, London, UK
[2] Institute of High Energy Physics, Austrian Academy of Sciences, Vienna, Austria

At the horizon 2050, our physics textbooks will have to be rewritten. The contributions in the first chapter of the EPS Grand Challenges explain why. Will all or many of the open questions be answered at the horizon 2050? There is justified hope, supported by a plethora of theoretical developments and experimental facilities on Earth and in space. Will new questions arise? You bet.

The contributions in the first chapter of the EPS Grand Challenges reflect the main research directions that are undertaken to find an answer to the many open questions.

The Higgs boson - When the Higgs boson was found in 2012 at CERN's Large Hadron Collider (LHC) in Geneva, history was made. The Higgs particle, and its associated field, are the reasons why atoms, stars, galaxies, and people are tangible entities. In addition, a tiny asymmetry between matter and antimatter that developed soon after the Big Bang, made it possible that we can exist at all. Without the Higgs boson and this asymmetry, only radiation would permeate the Universe. Fig. 1 shows collision

▲ Thousands of galaxies flood this near-infrared image of galaxy cluster SMACS 0723. High-resolution imaging from NASA's James Webb Space Telescope combined with a natural effect known as gravitational lensing made this finely detailed image possible. @NASA, ESA, CSA, STScI



▲ **FIG. 1:** Decays of a Higgs boson into a Z boson and a charm-anticharm quark pair, seen by the ATLAS and CMS Collaborations. In the ATLAS event, the Z boson decays into two muons depicted by the red tracks, whereas the charm-anticharm quark pair is not directly visible, since free quarks cannot exist. They hadronise, thus producing collimated sprays of particles around the original flight directions of the charm or anticharm quarks. In the CMS event, the Z boson decays to an electron and a positron, depicted by the green tracks. In both ATLAS and CMS the two charm-anticharm quark jets are depicted by blue or yellow cones. © CERN, for the ATLAS and CMS Collaborations

▲ **FIG. 2:** The heart of the XENON1T project, the Time Projection Chamber TPC after assembly in a clean room. @XENON1T team.

events with a Higgs boson decaying into a Z boson and two particle jets from charm-anticharm quarks, recorded by the ATLAS and CMS experiments at CERN. These events represent just a few of the possibilities how the Higgs boson can decay.

Detailed studies of the Higgs boson at current or future colliders, as well as precision measurements of the properties of matter and antimatter at a multitude of different experiments will reveal how the standard model of particle physics has to be amended.

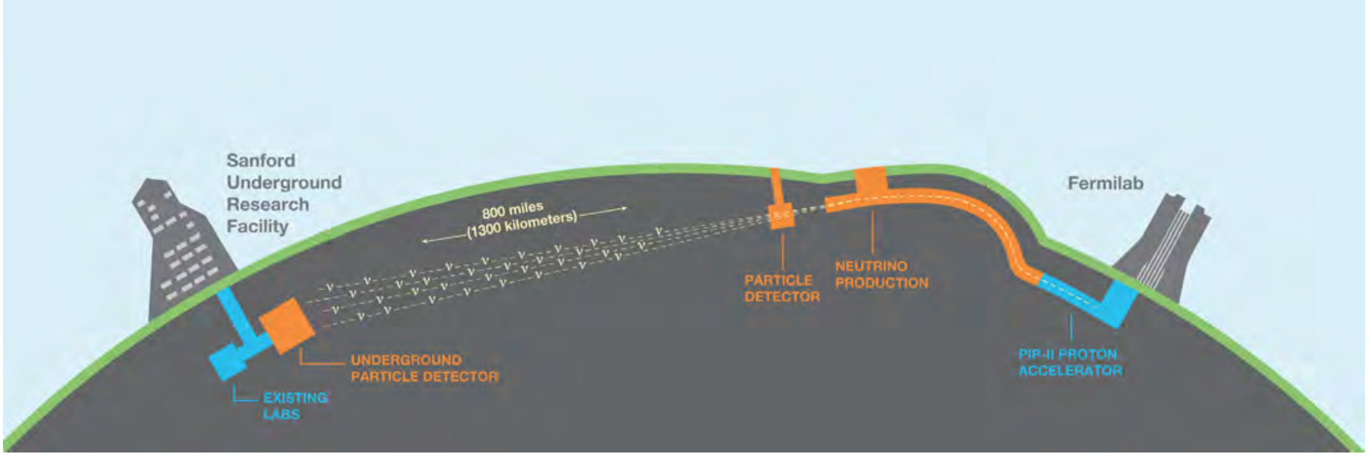
Read more: Particle physics: physics beyond the standard model, Freya Blekman.

Dark matter and dark energy - That it needs to be extended is evident. It does not contain dark matter, whose existence was already manifest decades ago. Another phenomenon, only discovered in 1998 through the study of the brightness of supernovae as a function of their distance, is dark energy, which makes our Universe expand in an accelerated fashion. Known or "visible" matter, the so-called baryonic matter, only accounts for 5% of the Universe, and is well described by the standard model of particle physics. The rest are dark matter (27%), and dark energy (68%). We have hardly any clues, but many ideas of what they could be (Fig. 2).

Read more: What is the Universe made of ? Searching for dark energy and dark matter, Emmanuel N. Saridakis and Jochen Schieck.

Neutrinos - Although postulated already in 1930, neutrinos are another category of particles that are still mysterious. It was only ascertained in the 1990's that they have mass, in contrast to the assumption in the standard model of particle physics, and that they come in different

▼ **FIG. 3:** Cutaway illustration showing the path of neutrinos in the Deep Underground Neutrino Experiment. A proton beam is produced in Fermilab's accelerator complex. The beam hits a target, producing a neutrino beam that travels through a particle detector at Fermilab, then through 1,300 km of earth, and finally reaches the far detectors at the Sanford Underground Research Facility. @FNAL.



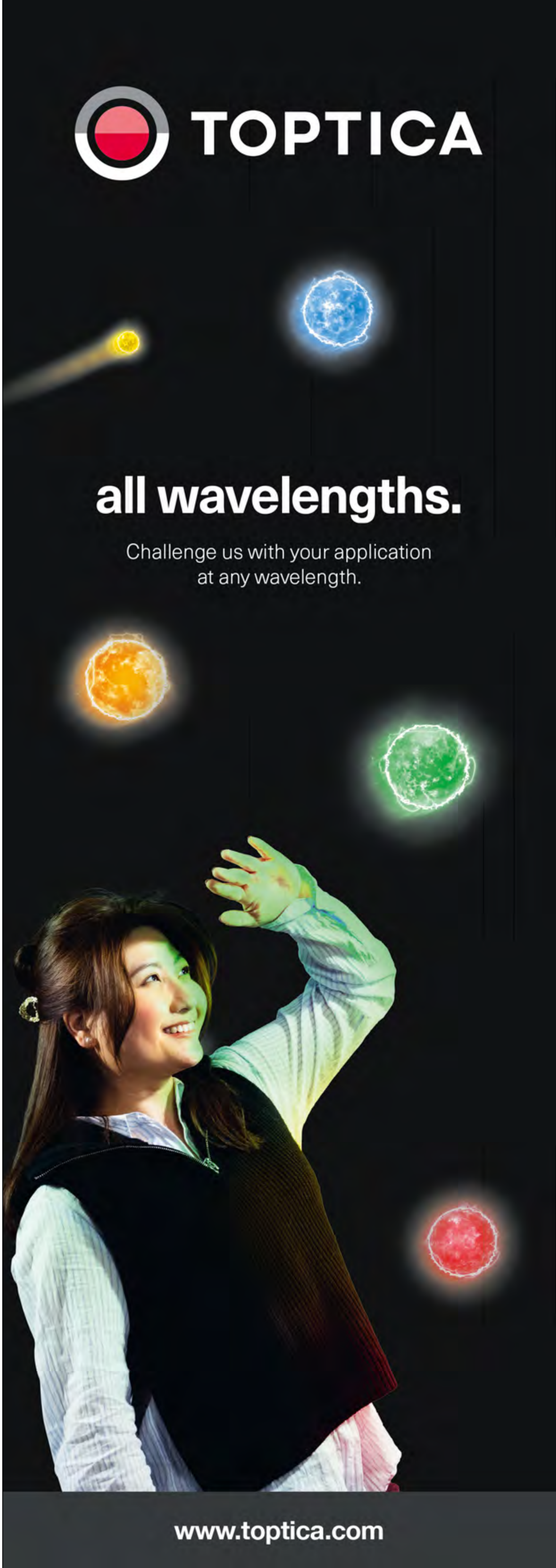
> **Read more in Chapter 1 of the EPS Grand Challenges.**

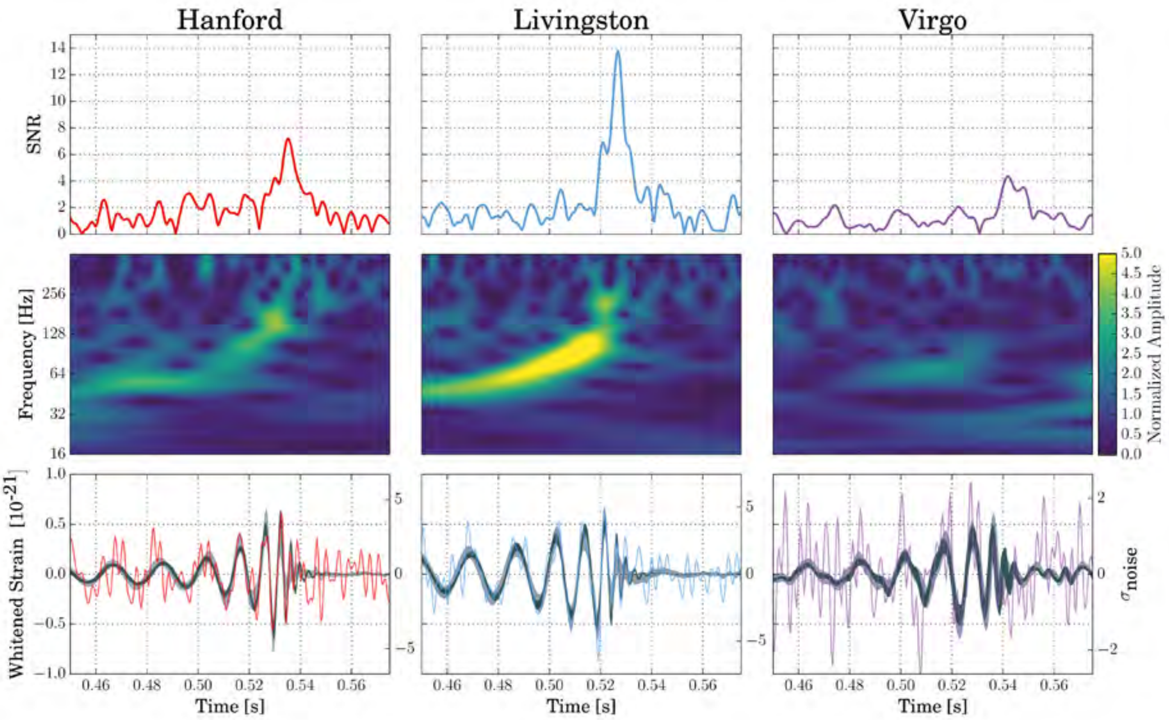
flavours that can transform into each other. There might even be more varieties – sterile neutrinos, which do not interact through the forces described by the standard model, but only through gravity (Fig. 3).

Gravitational waves - Gravity is so present in our everyday life and the movements of objects in the cosmos, it is the least understood force, and is not part of the standard model of particle physics. We do not even have a quantum-mechanical formulation of the theory of gravity yet, which would allow us to describe this force down to the smallest scales of the Universe. Our current understanding is based on Einstein's theory of general relativity, which however breaks down at the Big Bang and the centre of black holes. Everywhere else, it has so far been proven to be perfectly descriptive and accurate. The spectacular direct discovery of gravitational waves in 2015 – ripples in space-time predicted to arise from violent events in the cosmos, such as mergers of black holes or neutron stars – confirmed it once more. The first observation of a gravitational-wave event on 14 August 2017 in the VIRGO interferometer in Italy, hosted by the European Gravitational Observatory, together with the corresponding signals measured in the two LIGO detectors in the United States, at Hanford (Washington) and Livingston (Louisiana), respectively, is depicted in Fig. 2.
Read more: Quantum gravity – an unfinished revolution, Claus Kiefer

Multi-messengers astronomy - The discovery of gravitational waves has further opened up a new field called multi-messenger astronomy. We are no longer limited to observing the sky with our eyes or with telescopes detecting light or other electromagnetic waves, but we now also have gravitational waves, and neutrinos, at our disposal as messengers from cosmic sources. We can study all kinds of signals in a coordinated fashion, in experimental facilities around the globe and even in space.
Read more: A gravitational universe : black holes and gravitational waves, Nelson Christensen.

Nuclear physics - There are many bridges between the smallest and the largest scales. Nuclear physics, with its quest to understand the origins of known matter, from the primordial soup made of quarks and gluons, the protons and neutrons, the atomic nuclei, to the formation of the heavy chemical elements in explosions of stars, connects these infinities. It also has a large potential for technological spin-offs, such as nuclear fusion to ensure the supply • • •



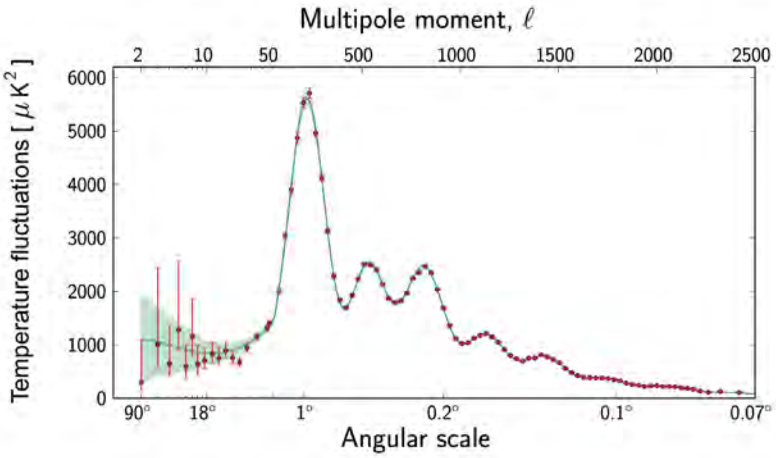


▸ **FIG. 4:** First gravitational-wave event (GW170814) detected by VIRGO, and seen in LIGO. © LIGO and VIRGO Collaborations

of electric power, and medical applications such as cancer therapy, as well as efficient and affordable isotope production for diagnostic purposes. For the latter, imaging techniques using artificial intelligence and other means are drivers for improving diagnostic accuracy, rapidity, and the comfort of patients. Astrophysics and high-energy particle physics are also connecting the scales, and have given rise to the new field of astro-particle physics. *Read more: Nuclear physics: the origin of visible matter in the Universe, Angela Bracco*

Cosmology - with its quest to understand the largest scales and nothing less than the fate of our Universe, cosmology needs information about its smallest components. Amongst others, measurements by space observatories such as Planck operated by the European Space Agency have helped establish the now widely accepted standard model of cosmology, as can be seen from Fig. 5. For the time being, we are at a turning point in the knowledge about the future of our Universe. Soon we should know more about its evolution, and in particular, whether it will be confirmed to expand continuously forever, or to rip apart, or even contract again.

▾ **FIG. 5 :** The power spectrum as measured by Planck. The green curve represents the best fit of the standard model of cosmology, currently the most widely accepted scenario for the origin and evolution of the Universe to the Planck data. © Planck Collaboration and ESA



Other research areas - The stars, the sun and the planets, including our own, still have secrets themselves. Their formation and evolution are vibrant research areas, tackled through computations and observations, and exploiting a multi-disciplinary approach. The study of exoplanets has also become a central subject in astrophysics. More down-to-earth, geophysics addresses topics that can affect us all, such as volcanic eruptions, earthquakes, or even changes in the Earth's magnetic field. The understanding of these phenomena can help predict their occurrence, for the benefit of mankind.
Read more: Stars, the Sun, and planetary systems as physics laboratories, Patrick Eggenberger and Physics of the Earth's interior, Emanuel Dormy

Acknowledgement

The authors would like to thank Freya Blekman, Angela Bracco, Nelson Christensen, Emmanuel Dormy, Patrick Eggenberger, Claus Kiefer, Emmanuel Saridakis and Jochen Schieck for their valuable contributions to the EPS Grand Challenges project.

PHYSICS OF MATTER AND WAVES

Kees van der Beek – DOI: https://doi.org/10.1051/epn/2022503
CNRS - Centre for Nanosciences and Nanotechnologies, Palaiseau, France

The scales of length, time, and energy that are intermediate between the infinitely small and the infinitely large define the world we live in and that we experience. The relevant fundamental forces that act on these scales are, for nearly all phenomena, the gravitational and the electromagnetic forces. This is the subject of Chapter 2 of the EPS Grand Challenges

▲ **FIG. 1:** Interactions and emergence, illustrated by a water drop falling on a water surface. Because of the interaction between water molecules, the small drop has a visible effect over a large range, leading to the emergence of the ripple and the central rebound.

At the energy scales that characterise our world, the relevant physical approaches take atoms, ions, and electrons as fundamental building blocks of matter, and photons as those of light. The constituents, in the unimaginable vastness of their numbers and the fantastic variety of their possible arrangements, lead to the astounding complexity of our world and the dazzling phenomena it harbours. The world we experience is also the world on which we may intervene. When done in a controlled manner, this intervention – or experiment – belongs to the realm of science and technology. But even when we do not strive to control, our actions are still determined by the physical workings of the world's constituent building blocks and their interactions. When one comes to think of it, an atom itself is a hugely complex system. Mathematics abdicates when faced with the problem of providing an exact description of more than three interacting objects, and all atoms are in this situation: quarks make up hadrons, hadrons make up the atomic nuclei, and nuclei and electrons make up the atom. The internal organisation of the atom is the result of, for most elements, numerous "correlations". The simultaneous presence of several and often many interacting particles lead to the organisation of matter. This is even more true when one assembles atoms into molecules, atoms and molecules into liquids and solids, and liquid and solid components into complex systems. We witness that the forces •••

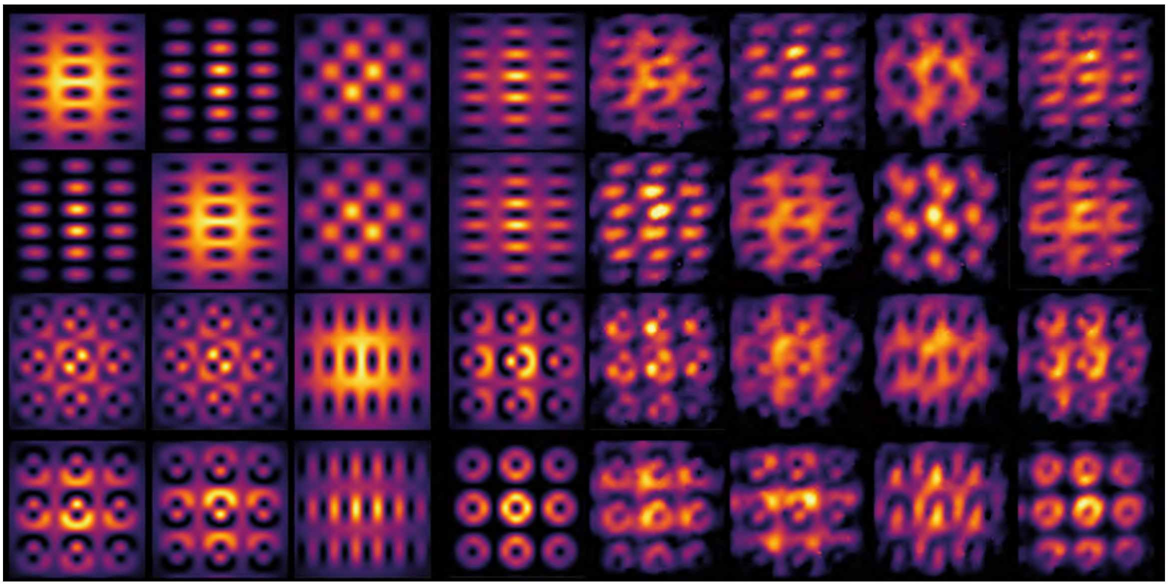
▲ **FIG. 2:** Manipulation of light. This example illustrates the numerical design of a microscale optical system separating different spectral waves and funnelling them into different waveguides. Adapted from [1] with permission from APS.

which objects around us exert on each other, and the phenomena that emerge, are the net result of their internal, physical organisation. The myriad particles involved and the manner in which they can interact and can be made to interact vouch for complexity. In chapter 2 of the EPS Grand Challenges work done in the various research fields are presented.

Quantum many-body systems - The study of "Quantum many-body systems and emerging phenomena" is concerned with the organisation of matter and the excitations its constituents can undergo when stimulated by light or other, impinging, particles. It describes how "emergent" behaviour can emerge from the interaction of many constituent particles (see Figure 1 for a parabolic illustration), and how the quantum mechanical nature of our world determines the nature of the objects that constitute it, even though we may not at all be aware of such. It also describes when a quantum description is needed, that is, when the conditions of observation are such that coherent interactions and propagation of light and particles are guaranteed. When the quantum mechanical coherence of light and matter is disturbed in the process at hand, we may resort to what has become known as the "classical description". *Read more: Lucia Reining, Quantum many-body systems and emerging phenomena.*

New materials - In searching for new materials the – even limited - understanding of the organisation of matter helps mankind fashion the materials and tools need to tackle the world's challenges and problems. Here, in principle, there is nothing new. Did not the smithies and rock-hewers of prehistoric and early historic times draw on their experience to fashion stone and metal tools? Now, the formidable scientific progress accumulated over the last two centuries allows for mankind to imagine and make materials according to need, in a sustainable and controlled manner, at all scales down to that of the very constituent atoms. New and urgent challenges are to take into account the availability of material and energetic resources and to design those material assemblies and those processes that are most appropriate for a given application, choosing from the many millions of materials that nature would allow.
Read more: Claudia Draxl and José Maria de Teresa Nogueras, The search for New Materials.

Manipulating atoms and photons - Nowhere does the force of science have an impact as great as when matter and light are manipulated on the smallest of scales – the nanometer (*i.e.* 10^{-9} m) or below. "Manipulating Atoms and photons, photonics and nanophysics" shape today's and tomorrow's technologies and allow us to dive into



▶ **FIG. 3:** Twisting Light Beams on Demand: Beams of light with phase-structured wave fronts provide a robust, high-dimensional medium for metrology and communication applications (from A.R. Cameron *et al.*, Phys. Rev. A 104, L051701 (2021) © APS

the smallest length scales defining materials and the systems they can constitute and, indeed, back into the quantum realm. The understanding of how interactions between particles manifest themselves differently depending on the length scale we are working on and how the quantum mechanical nature of these interactions can be brought out, allows one to put both to work to define entirely new tools, systems, and paradigms (see *e.g.*, Figure 2).
Read more: Jean-Jacques Greffet, Antoine Browaeys, Frédéric Druon, and Pierre Sénéor, Manipulating photons and atoms: photonics and nanophysics.

Extreme light - What goes for matter also goes for light, and what goes for space also goes for time. Recent and astounding advances now allow one to fashion extremely bright light beams, extremely short light pulses, or a combination of both, giving rise to the realm that has become known as "Extreme Light". Extreme brightness allows us to examine the structure of matter, its organisation, and its response to excitations in the very finest details – for it is those details that most often give away the fundamentals at stake in determining the nature of the studied object in the first place. Ultra-short and bright pulses allow one to make "movies of matter". Much as stroboscopic illumination of moving beings can reveal the gestures in motion, pico- and femto-second illumination of matter unveils the dance of electrons in matter: how matter is excited, how matter reacts, how matter transforms. Extremely spectacular results with high-stake implications in many fields (chemistry, biology, medicine…) are to be expected here. Moreover, being able to intervene at the rhythm of matter itself allows us to reorganise it, yielding yet another tool for the creation of new (quantum) states of matter designed as tools to face the challenges of humankind.
Read more: Franck Lépine, Jan Lüning, Pascal Salières, Luis Oliveira e Silva, Thomas Tschentscher, Antje Vollmer, Extreme Light.

Extended classical systems – In the EPS Grand Challenges, the summary of the Physics of Matter and Waves in the world as we know it and discover it is completed by the description of classical systems with numerous degrees of freedom and the multiplicity of interactions in systems that are not necessarily characterised atomic length and time scales and quantum coherence. This opens the way for the most complex of organisations of matter as we know it: life itself.

Acknowledgement

The authors would like to thank Marco Baldovin, Antoine Browaeys, Claudia Draxl, Frédéric Druon, Giacomo Gradenigo, Jean-Jacques Greffet, Franck Lépine, Jan Lüning, Lucia Reining, Pascal Salières, Pierre Seneor, Luis Silva, José Maria de Teresa, Thomas Tschentscher, Antje Vollmer and Angelo Vulpiani for their valuable contributions to the EPS Grand Challenges project.

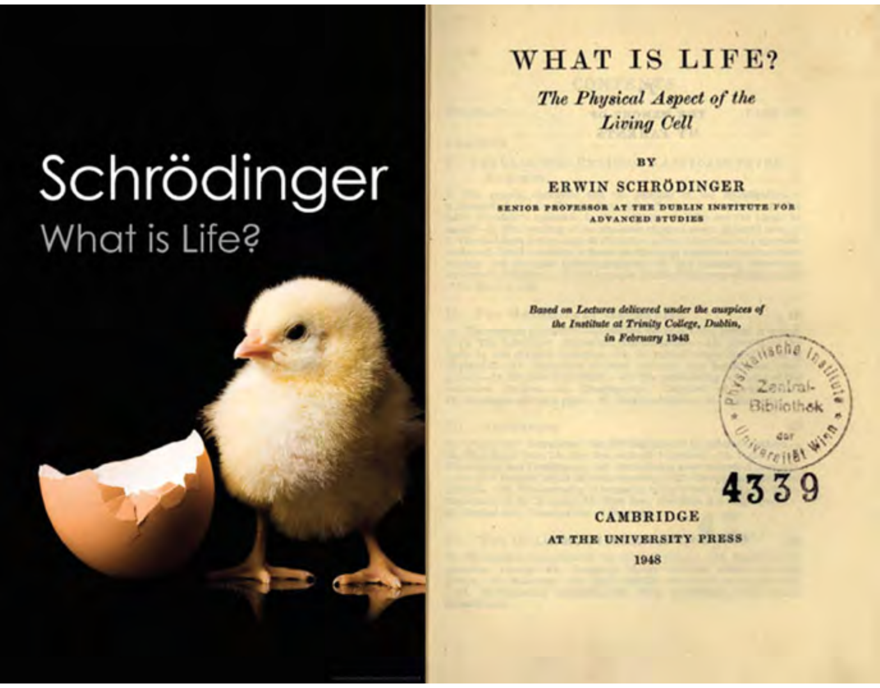
PHYSICS FOR UNDERSTANDING LIFE

Felix Ritort[1] **and Bart van Tiggelen**[2] DOI: https://doi.org/10.1051/epn/2022508

[1] Small Biosystems Laboratory, Condensed Matter Physics Department – Facultat de Física – Universitat de Barcelona, Spain
[2] University Grenoble Alpes, CNRS, LPMMC, Grenoble, France

"Living" matter distinguishes itself from "ordinary" matter by its capacity to grow, to reproduce or to multiply, and most of all by its autonomous functional activity, baptised "intelligence", to sense its environment to adapt or to survive. This last feature truly is one of the miracles of life. Find out more in Chapter 3 of the EPS Grand Challenges.

Our current knowledge of life is relatively recent. The "molecule of life", Deoxyribose Nucleic Acid or DNA, was first discovered by Miescher in 1860. The discovery of the double helix structure by Watson and Crick in 1951, and the determination of its sequence of nucleic acids by Sanger and Coulson in 1975 have been major breakthroughs of the last century. Can science discover what conditions have facilitated the origin of life on Earth? Does some kind of "life" exist on extra-terrestrial planets? Can we create "artificial life" that self-replicates or has intelligence? Can we design and implement "artificial intelligence"? These challenges are hopefully within reach on the Horizon 2050. Is life nothing but "vital dust", *i.e.* a natural consequence of non-equilibrium physics and chemistry, or was it rather a "magnificent accident"? Famous physicists like Erwin Schrödinger and Freeman Dyson struggled with the role of physics in the origin of life. Schrödinger wondered how life manages to stay out of equilibrium while respecting the Second Law. Dyson argued that metabolism and replication could have originated separately and that "life actually began twice". Physics is not enough for understanding life, but life may reveal new physics. To understand life, we need interdisciplinary collaborations between biologists, computer-scientists, chemists, physicists, astrophysicists and engineers. Chapter 3 of the EPS Grand Challenges is devoted to the field of physics for understanding life.



WHAT IS LIFE?
The Physical Aspect of the Living Cell
BY
ERWIN SCHRÖDINGER
SENIOR PROFESSOR AT THE DUBLIN INSTITUTE FOR ADVANCED STUDIES

Based on Lectures delivered under the auspices of the Institute at Trinity College, Dublin, in February 1943

CAMBRIDGE
AT THE UNIVERSITY PRESS
1948

▾**FIG. 1:** What is life? by Erwin Schrödinger (source: Wikipedia)

J.D. Watson and F.H.C. Crick, A structure for deoxyribose nucleic acid. Nature ***171****, 737 (1953).*
F. Sanger and A.R. Coulson, A rapid method for determining sequences in DNA by primed synthesis with DNA polymerase, J. Mol. Biol. ***94*** *(3): 441 (1975).*
C. De Duve, Vital Dust (Basic Books, 1995).
E. Schrödinger, What is life?, Cambridge University Press (1944).
F. Dyson, Origins of Life, Cambridge University Press (1992).

Where do we come from? How life on Earth began remains an unsolved, complex scientific problem. After the brilliant experiments by Pasteur and Tyndall in the nineteenth century, the concept of "spontaneous generation" of life from non-living matter was rejected for once and for all. Life may have emerged only 400 million years after the "Hadean" Earth was created (Hades was the king of the ancient Greek underworld), only 200 million years after liquid water had first appeared. The absence of a well-preserved crust older than 3.3 billion years makes it difficult to get a precise information about the chemical composition of the Hadean Earth. The time variations on all scales of the Earth-Sun connection must have played a major role in the chemistry that created life. Stellar evolution models tell us that the young Sun was 70 % fainter than today. The "faint young Sun paradox" states that this low flux implies water on Earth to be frozen until well beyond the Hadean age, which we know is not true. Greenhouse gases such as CO_2 must have been present, heating up the atmosphere much like they do today. The rapid rotation of the young Sun in only a few days led to strong magnetic activity and intensive space weather, so that energetic X-ray fluxes must have been up to 100 times larger than today.

The presence of liquid water is a major condition for life to form, but other habitability conditions exist, such as the presence of organic molecules and energy sources – providing at least 150 kJ/mol - to initiate prebiotic chemistry. Energetic solar photons must have provided a lot of this energy. Organic molecules such as HCN and CH_2O could also have been created by the lightning-triggered dissociation of carbon-dioxide and abiotic methane. A mostly reducing (oxygen-poor) early atmosphere with energetic sparks could have been a play-ground for prebiotic chemistry and a world-famous "Miller-Urey" experiment supporting this vision was done in 1952. Carbonaceous meteorites impacted the Earth and brought also many organic compounds, including amino acids. Where exactly prebiotic chemistry took place is still subject to a large debate. Energetic radiation does not penetrate more than 1 cm in water.

*H.J. Cleaves, Prebiotic Chemistry: What We Know, What We Don't, Evolution: Education and Outreach **5**, 342 (2012).*

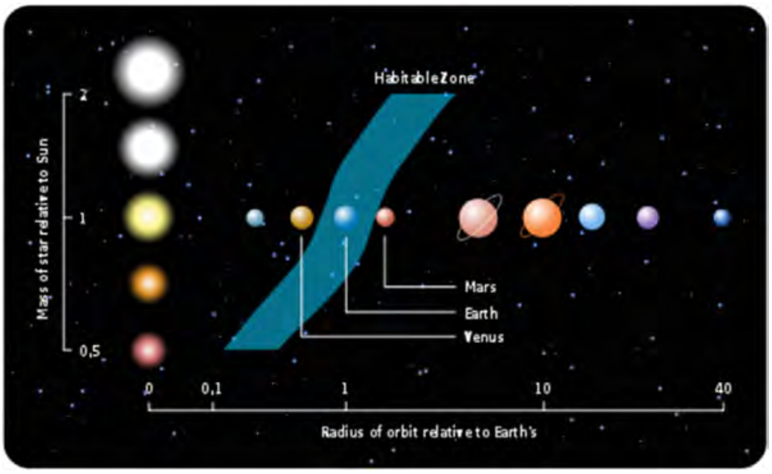
*C. Sagan and G. Mullen, Earth and Mars: Evolution of Atmospheres and Surface Temperatures,Science. **177** (4043): 52 (1972).*

*H.C. Urey, On the early chemical history of the Earth and the origin of life, P.N.A.S. **38**, 351 (1952).*

*S.L. Miller, Production of Amino Acids Under Possible Primitive Earth Conditions, Science **117**, 528 (1953).*

Life for understanding new physics. In his 1944' beautiful essay Erwin Schrödinger wrote: *"The large and important and very much discussed question is: how can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?"*. The marvellous complexity of living matter raises the question of whether biology hides new, emerging physical laws awaiting discovery. From the Brownian motion of pollen grains to cell motility, animal motion, the many behaviours of active matter, and the evolution of bacterial populations, the interface between biology and physics offers an unprecedented wealth of new phenomena that can be investigated at an exquisite level of detail. For example, single-molecule techniques permit us to monitor how a protein folds and measurements of energies with 1 kT (≈ 10^{-21}J) accuracy reveal how a molecular motor moves one step at a time. By increasing the bar of spatial, temporal, and energy measurement accuracy, we hope to uncover vital discrepancies between our current theoretical knowledge and experiments on biological systems. Teleonomy is the continuous "purposefulness" of living beings to sleep, feed, trade, play, laugh, *etc.* They are not found in non-living matter where just the laws of physics and chemistry prevail. Does it escape our comprehension? What is the role of physical information in biology? Does information set a new paradigm for emerging complexity that connects biology to quantum physics? All these are relevant questions waiting for an answer.

*F. Ritort, The Noisy and Marvellous Molecular World of Biology, Inventions **4.2**, 24 (2019).*



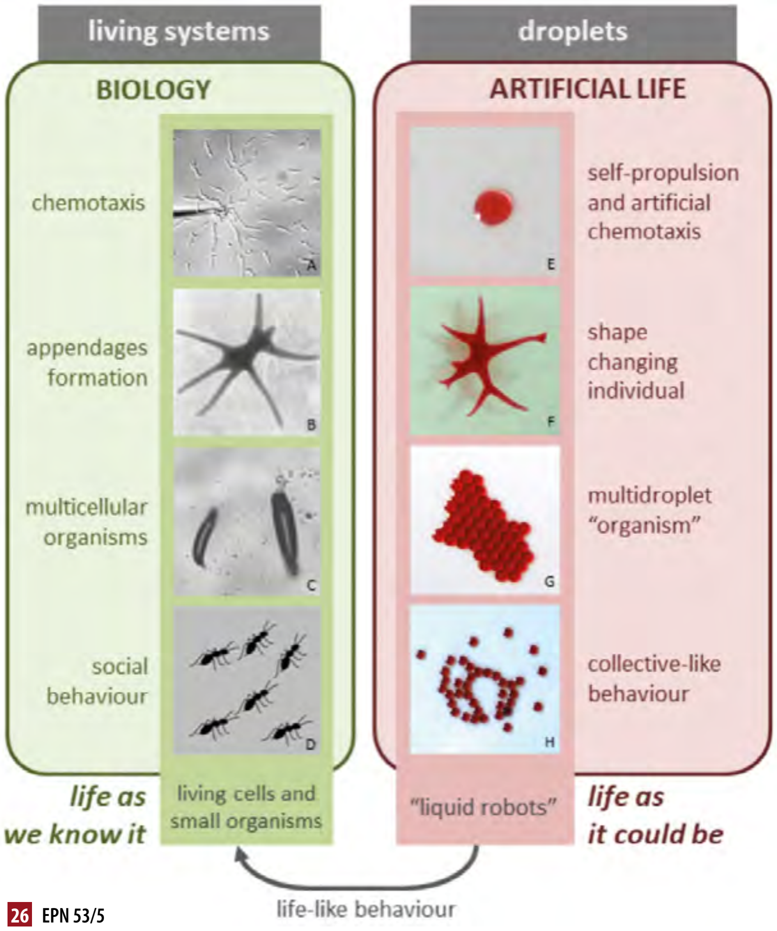
▲ **FIG. 2:** The habitable zone predicted on the basis of liquid water present at the surface of the planet. (source: Wikipedia)

What is the nature of the human mind? Artificial intelligence (AI) covers all techniques that enable machines to solve tasks like humans do. AI applications are immense, from medicine to robotics and basic science. AI has seen fast growth since the fifties when cybernetics and feedback, the branch of science introduced by Wiener in 1948, took off as an effort to understand information processes in machines and living beings. The Greek term "cybernetics" (*kybernetiké*), the art of guiding, was introduced by Ampère in his classification of sciences published in 1834, subsequently taken up by Maxwell. Subsequent work by Bertalanffy on the general theory of biological systems, Maturana and Varela on *autopoiesis* (the idea of self-sustaining cycles), Von Neumann, Shannon, and Gabor on automatic systems have set the basis of modern AI. Good old-fashioned AI (GOFAI), as it is called nowadays, embraces the power of using basic symbols (words, pictures, actions, *etc.*) to represent physical patterns to build up high-order symbolic structures to be manipulated with programs and algorithms. A key limitation of GOFAI is that programs can neither adapt themselves nor acquire new knowledge on their own, which led to the "AI winter" in the eighties without significant progress. The subsequent development of connectionism in artificial neural networks and statistics-based inference methods

(machine learning) that allow data internal structure to evolve, has led to new functionalities. In the current view, intelligence stands for the ability to avert the ever-present threat of the exponential explosion of search options. What about consciousness? If brains can be considered as probabilistic prediction machines they must somehow deal with uncertainty. Is this related to consciousness? Are we going to understand consciousness one day?
N. Wiener, Cybernetics or Control and Communication in the Animal and the Machine, MIT press (2019)
J.C. Maxwell, On Governors. Proceedings of the Royal Society of London ***16****, 270 (1868)*
O.A. Newell and A.S. Herbert, Computer science as empirical inquiry: Symbols and search, ACM Turing award lectures, 2007 (1975).

Can we build artificial life? Artificial life (ALIFE) aims at building sustainable self-replicating systems resembling living beings. ALIFE comes in three forms: computer-designed AI programs and algorithms (soft ALIFE), hardware-based robots (hard ALIFE), and chemical and biochemical systems with life-like behaviour (wet ALIFE). The basic tenet of ALIFE is that if Nature has found one way of organizing living matter, other (unknown) ways should exist. Can we build synthetic cells endowed with homeostasis, self-reproduction, and evolution? Man-designed cell-like droplets exhibit limited properties and functionalities, such as self-propulsion, artificial chemotaxis, organism-like multi-droplets, collective-like behaviours, *etc.* Building synthetic ALIFE systems represents a daunting task ahead. Besides possessing basic properties such as robustness, autonomy, efficiency, recycling, intelligence, self-repair, adaptation, self-replication, *etc.*, they must show open-ended evolution and teleonomy. Are we ever going to leap this gap?
A. Pross, What is life?: How chemistry becomes biology. Oxford University Press, 2016.

▾ **FIG. 3:** Life-like behaviour, comparison between living systems in biology and droplets in artificial life.



Is there anybody out there? The question whether extra-terrestrial life exists is as old as mankind. No matter how small the probability is for life to emerge, its existence "somewhere, sometime" in the huge Universe is largely accepted by scientists. The Drake equation, actually proposed as an agenda item for a meeting on alien communications in 1961 but today argued to be one of the most important equations in science, gives estimates of up to many millions of detectable alien civilisations in our own Galaxy. The famous paradox raised by Enrico Fermi during an after-dinner talk in 1950 states that if there are really so many, then "where are they?". One possible answer is that intelligent civilisations tend to self-destruct.

With the recent observation of exoplanets, the first proof of extra-terrestrial life may be within reach. Will it have the same biochemistry that created life on Earth? The establishment of a list of "biosignatures" - molecules whose origin we believe requires a biological agent - has top-priority. Molecular oxygen is a clear biosignature, and is hardly found elsewhere in our solar system. A molecular biosignature must be stable with respect to the local planetary environment, though its detection may be false alarm due to abiotic reactions. Within our solar system several bodies such as Mars, Jupiter's moon Europe and Saturn's moon Titan have been identified as possible candidates to host or to have hosted life. Sample-return missions and in-situ search for "biosignatures" started with the Viking lander missions to Mars in 1976 and continue today with the rover Perseverance. Indications exist that Mars might host methane-producing micro-organisms at its subsurface. The complication on Mars is that many identified biosignatures were possibly destroyed by (per)chlolates.

Our knowledge about exoplanets outside the solar system entirely depends on remote sensing. Today, more than 4000 exoplanets have been identified. The recently launched James Webb telescope will facilitate the study of infrared absorption lines in the spectra of exoplanet atmospheres, observed while transiting in front of the star, and possibly due to biosignatures. The perfect exoplanet to observe "Earthian" life would be an Earth-sized planet in an Earth-like orbit around a Sun-like star. Unfortunately, due to observational selections effects, few such perfect exoplanets are currently known. A recently observed candidate is one of the

PHYSICS FOR HEALTH

Ralph W. Assmann[1], **Giulio Cerullo**[2] **and Felix Ritort**[3] – DOI: https://doi.org/10.1051/epn/2022504
[1]DESY, Hamburg, Germany
[2]Dipartimento di Fisica, Politecnico di Milano, Piazza L. da Vinci 32, 20133 Milano, Italy
[3]Small Biosystems Laboratory, Condensed Matter Physics Department – Facultat de Física – Universitat de Barcelona, Spain

The fundamental research on the physics of elementary particles and nature's fundamental forces led to numerous spin-offs and has tremendously helped human well-being and health. This is the subject of Chapter 4 of the EPS Challenges for Physics.

▲ MRI scanning equipment ©iStockPhoto

Prime examples include the electron-based generation of X rays for medical imaging, the use of electrical shocks for treatment of heart arrhythmia, the exploitation of particle`s spin momenta for spin tomography (NMR) of patients and the application of particle beams for cancer treatment. Ten-thousands of lives are saved every year from use of those and other physical principles. A strong industry has developed in many countries, employing hundreds of thousands of physicists, engineers and technicians. Industry is designing, producing and deploying the technology that is based on advances in fundamental physics.

Major research centers have established and provide cutting-edge beams of particles and photons for medical and biological research, enabling major advances in the understanding of structural biology, medical processes, viruses, bacteria and possible therapies. Those research infrastructures serve tens of thousands of users every year and help them in their research. Modern hospitals are equipped with a large range of high technology machines that employ physics principles for performing high resolution medical imaging and powerful patient treatment. Professors and students at universities use even more powerful machines for conducting basic research in increasingly interdisciplinary fields like biophysics and robotics. New professions have developed involving physicists and reaching out to other domains. We mention the rapidly growing professions of radiologists, health physicists and biophysicists.


Optimize
Your
Process

▲ **FIG. 1:** Virtual Reality (VR), advanced user interfaces and telecommunications and robot technology combine to create an enhanced surgical experience.

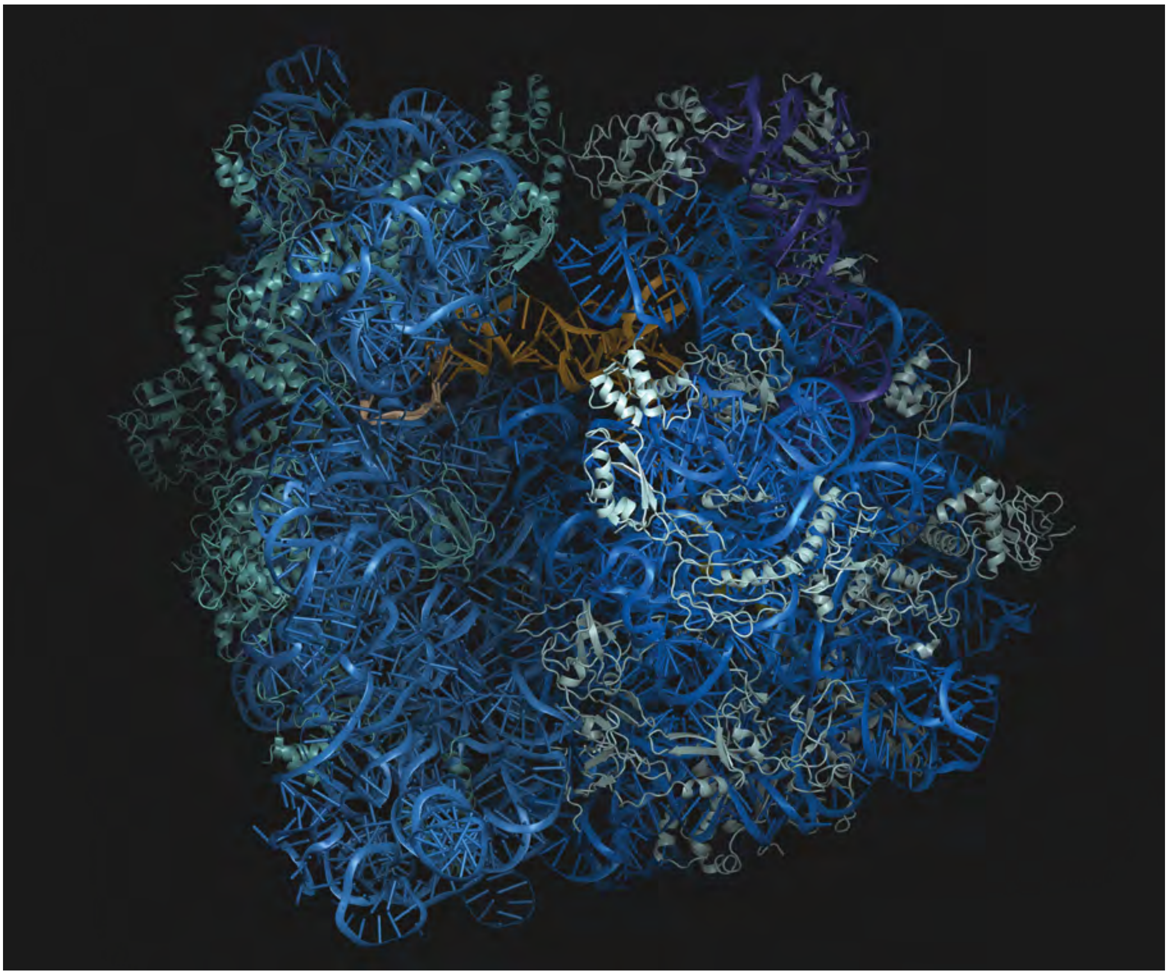
While physics spin-offs for health are being heavily exploited, physicists in fundamental research keep advancing their knowledge and insights on the biochemical mechanisms at the origin of diseases. New possibilities and ideas keep emerging, creating unique added value for society from fundamental physics research. Chapter 4 of the EPS Grand Challenges on physics for health does not aim to provide a full overview of the benefits of physics for health. Instead, the authors are concentrating on some of the hot topics in physics and health related research. The focus is put on new developments, possible new opportunities and the path to new applications in health.

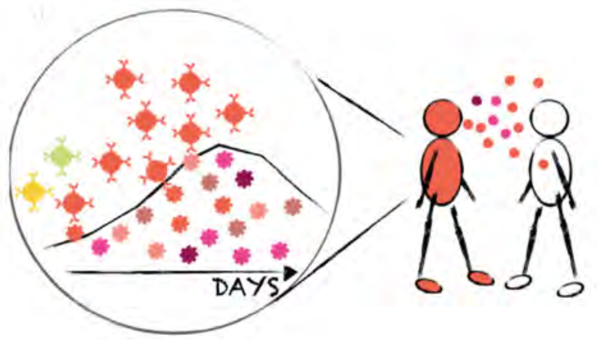
Using particle accelerators - Angeles Faus-Golfe and Andreas Peters describe the role of particle accelerators and the use of their beams for irradiating and destroying cancer cells. State of the art machines and possibilities for new irradiation principles, *i.e.* the FLASH effect, are introduced. As physics knowledge and technology advance, tumors can be irradiated more and more precisely, damage to neighboring tissue can be reduced and irradiation times can be shortened.

Using robotic systems - Darwin Caldwell looks at the promise and physics-based development of robotic systems in the macroscopic world, where they are complementing human activities in a number of tasks from diagnosis to therapy. Friedrich Simmel looks at the molecular and cell-scale world and explains how nanorobotics, biomolecular robotics and synthetic biology are emerging as additional tools for human health, for example as nano-carriers of medication that is delivered precisely [Fig. 1].

Using light - Henry Chapman and Jürgen Popp describe the benefits of light for health [Fig. 2]. Jürgen Popp is considering the use of lasers that have advanced tremendously in recent years in terms of power stability and wavelength tunability. Modern lasers are used in several crucial roles in cell imaging, disease diagnosis

▶ **FIG. 2:** The molecular structure of the ribosome, as determined by X-ray crystallography at DESY in Hamburg, showed researchers how this complicated nano-machine synthesises new proteins by reading genetic information encoded in messenger RNA molecules.





▲ **FIG. 3:** Within an infected host the cells of the immune system target existing viruses (and pathogens in general) by binding and neutralizing them. Each host has a vast repertoire of immune cells (denoted by different colors) from which those that best target the infection are chosen (same color as the viral strains). In some cases, these cells can further somatically evolve to increase their recognition power.

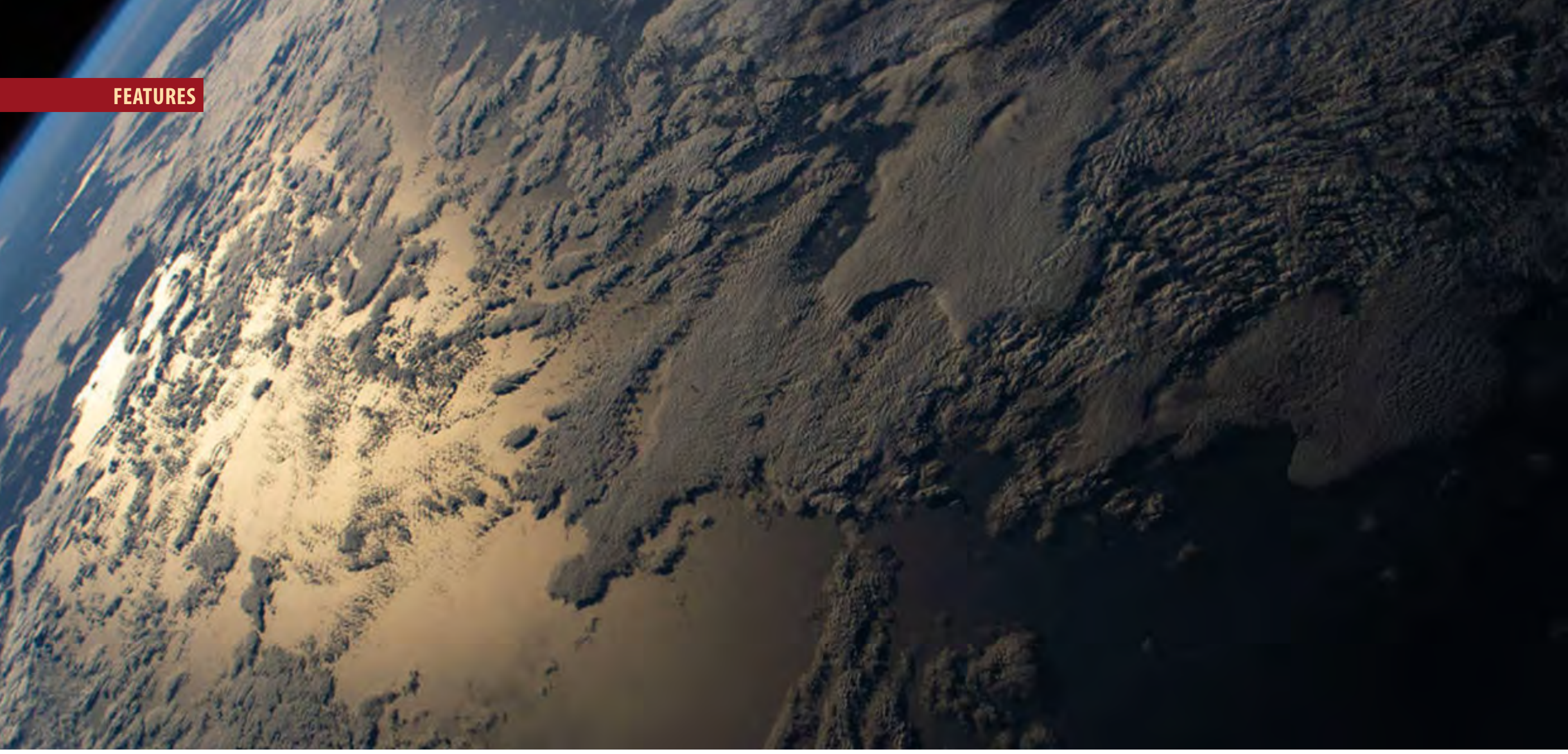
and precision surgery. Henry Chapman considers the use of free-electron lasers for understanding features and processes in structural biology. He shows that the advance of those electron accelerator-based machines has allowed a tremendous progress in the determination of the structures of biomolecules and the understanding of their function.

Pandemics - Aleksandra Walczak, Chiara Poletto, Thierry Mora and Marta Sales describe Physics research against pandemics, a multidisciplinary problem at the crossing of immunology, evolutionary biology and networks science. Pandemics is also a multi scales problem at the spatial and temporal levels: from the small pathogen to the large organism; and from the infective process at cellular scale (hours) to its propagation community-wide (months) [Fig. 3]. Simple mathematical models such as SIR (Susceptible-Infected-Recovered) have been a source of inspiration for physicists who model key quantities at an epidemic outbreak, such as the effective reproductive number R, in situations where a disease has already spread. A prominent example is the recent COVID-19 pandemics that has been more than a health and economic crisis. It illustrates our vulnerability where interdisciplinary & multilateral science play a crucial role to address a global challenge that is affecting societies at their core.

Outlook - Promise and progress in further diagnostics and therapies is also considered. Lucio Rossi explains the progress in magnetic field strength as it can be achieved with super-conducting magnets, while Marco Durante discusses the progress in charged particle therapy for medical physics.

Acknowledgements

The authors would like to thank Darwin Caldwell, Dana Cialla-May, Henry Chapman, Marco Durante, Angeles Faus-Golfe, Susanne Hellwage; Jens Hellwage, Christoph Krafft, Timo Mappes, Thomas G. Mayerhöfer, Thierry Mora, Andreas Peters, Juergen Popp, Petra Rösch, Chiara Poletto, Lucio Rossi, Marta Sales-Pardo, Iwan Schie, Michael Schmitt, Friedrich Simmel and Aleksandra Walczak for their valuable contributions to the EPS Grand Challenges project.



PHYSICS FOR ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

Luisa Cifarelli[1] **and Carlos Hidalgo**[2] – DOI: https://doi.org/10.1051/epn/2021505

[1] University of Bologna and INFN, Bologna, Italy – [2] Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain

One of the most crucial and challenging development of the last decades has been the discovery that environment is fragile. Read about it in Chapter 5 of the EPS Challenges for Physics.

▲ Sunlight glints above the Indian Ocean as the ISS orbited about 270 miles above the Earth near western Australia. Credit: NASA.

A discovery that shows that we cannot afford to delay the implementation of actions to tackle climate change if the long-term objective is to try limiting the increase in the global temperature of the planet at an affordable cost. Although the environment problem is too complex to admit simple solutions, recent developments illustrate how basic science, together with social awareness and political actions, can be successfully pulled together to avert an environmental tragedy. The contributions in chapter 5 of the EDP Grand Challenges present work done in a wide range of research areas illustrating how humanity not only has the responsibility to preserve our delicate planet but also the power to affect its environment. Together, they highlight the strength of fully interdisciplinary effort among physicists, mathematicians and chemists as well as multilateral science to address global challenges that affect societies at their core.

Nonlinear physics - Key concepts from nonlinear physics enable us to treat challenging problems of Earth sciences and climate projections. A reliable understanding of the Earth system is essential for the quality of life in a modern society. Natural hazards are the cause of most life and resource losses. The ability to define the conditions for a sustainable development of humankind to keep the Earth system within the boundaries of habitable states or to predict critical transitions and events in the dynamics of the Earth system are crucial to mitigate and adapt to Earth system related events and changes and to avert the disastrous consequences of natural hazards. Modelling climate requires the development of methods to simulate the interactions of the important drivers of climate, including atmosphere, oceans and land surface (Fig.1). *Read more: Earth system analysis from a nonlinear physics perspective, Juergen Kurths, Ankit Agarwal, Ugur Ozturk, Shubham Sharma, Norbert Marwan and Deniz Eroglu.*

Energy - Energy is the blood that moves today's society and is one of the factors that has decisively contributed to improving humanity's quality of life. The debate about the connection between energy sources and climate change has profound political and ethical consequences. It addresses the further development of energy storing

EDP Sciences launches a new books collection :

Institut d'Optique Graduate School Textbook

First to be published :

Optical Models for Material Appearance

Institut d'Optique Graduate School Textbook

Mathieu HÉBERT

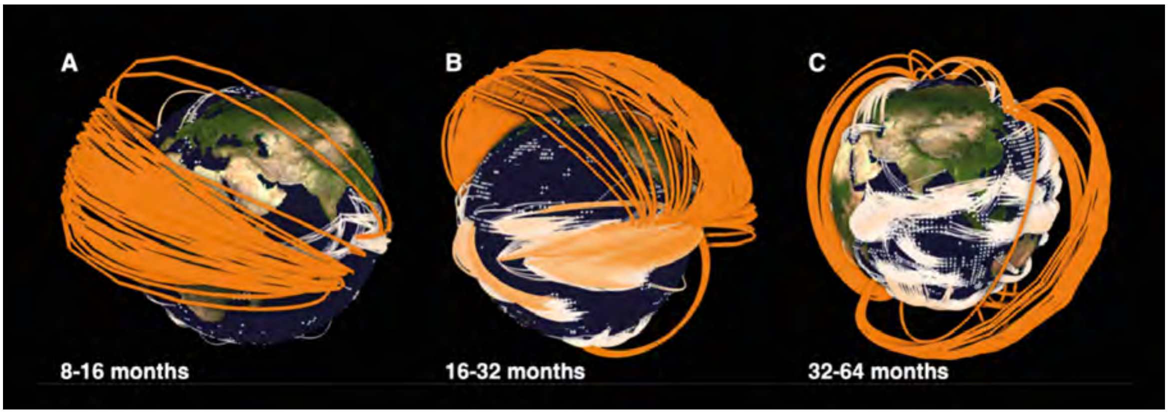
Optical Models for Material Appearance

This book is an introduction to the fundamental notions of optics which allows to understand the radiometric quantities measured with common devices, to learn how to analyze them, and to review some classical optics-based predictive models for various types of materials and structures.

The author, **Mathieu Hébert**, is professor assistant at Institut d'Optique Graduate School

ISBN 978-2-7598-2647-6
260 pages, 95 €

On sale on laboutique.edpsciences.fr (English books section)

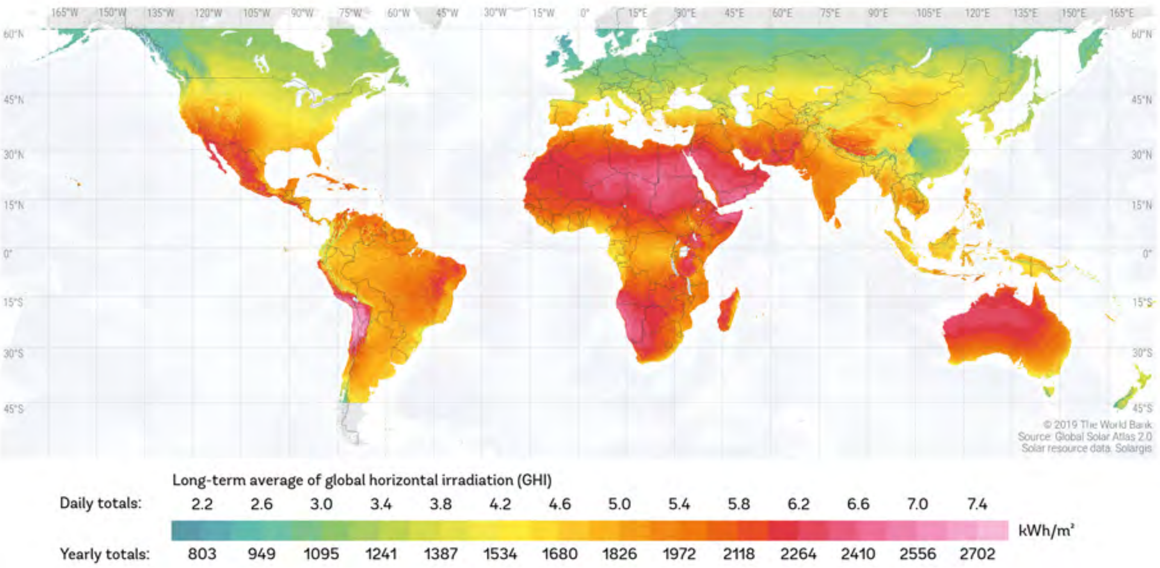


▸ **FIG. 1:** Spherical three-dimensional globe representation of the long-range teleconnections at different timescales in sea surface temperature network.

systems and of energy sources, like solar, wind, nuclear fission as well as the quest for nuclear fusion since the dominance of fossil fuels must decline (Fig. 2). It highlights the potential challenges and opportunities in the development of global energy systems, emphasising how deeply interconnected the energy and climate debates are. Now the physics and technology strands need further convergence and integration for the development of massive and sustainable energy sources. From this perspective the next few decades will be crucial to demonstrate the scientific and technical viability of fusion as an energy source by integrating the acquired knowledge in physics such as confinement and engineering optimisation, *e.g.* tritium technologies (Fig. 3).
Read more: Solar Energy, Robert Pitz-Paal and Bernd Rech.
Wind Energy. H. - J. Wagner.
Energy Storage, Søren Linderoth.
Fission Energy, Marco Ripani.
Fusion energy Development, Alberto Loarte.

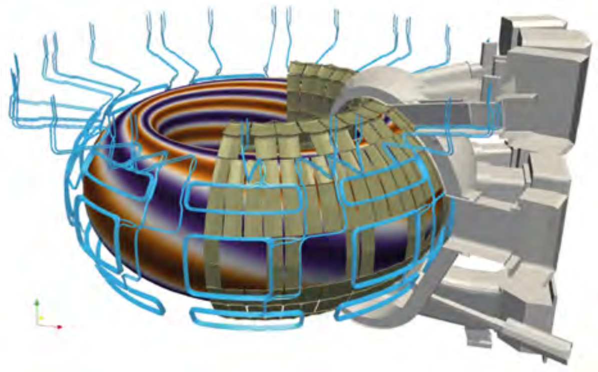
Green cities and transport - The invention of the combustion engine radically transformed industrial and personal transport and, consequently, our social organisation system. Improving the performances of batteries and fuel cells cannot be based exclusively on an empirical approach; it requires a deeper understanding of the complex multi-scale phenomena occurring in batteries and fuel cells. This challenge can be achieved by making use of computational simulation in combination with advanced characterisation techniques. Therefore, significant effort must be devoted to model validation against experiments.
Read more: Green cities and transport, Natalio Mingo; Gérard Gebel; Philippe Azais; Thierry Priem; Tuan Quoc Tran; Didier Jamet; Florence Lefebvre-Joud; Simon Perraud.

Environmental safety - Hazardous wastes and materials are diverse, with compositions and properties that vary significantly between industries and related energy sources. Challenges include air quality avoiding and reducing pollutant emissions, access to safe drinking water and food, economics and scale of waste management as well as public acceptability. From a chemical perspective environmental emissions and waste disposal can be managed to meet sustainable development criteria. Technical innovation is required to handle the foreseen burst of chemicals on environmental safety and health.
Read more: Environmental Safety, Jacob de Boer



© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis

▸ **FIG. 2:** The solar energy distribution is quite inhomogeneous on the earth surface. As the output of solar energy converters is almost proportional to its input, the cost of solar energy for both PV and CSP is strongly related to the selected site.



▲ **FIG. 3:** Magnetic confinement fusion plasmas maintain equilibrium by the magnetic fields creating a force that opposes the expansion of the hot plasma and this equilibrium may become unstable. These instabilities (so-called magneto-hydrodynamic instabilities) impact directly the achievable fusion power production and therefore their control is crucial. The figure shows the set of 27 coils (in blue) to control edge instabilities in ITER.

Space weather - Space weather describes the way in which the Sun, through emergence of magnetic field into its atmosphere, flares, coronal mass emissions, high-energy particles and subsequently induced space conditions, impacts human activity and technology both in space and on the ground (Fig. 4). It causes substantial socio-economic impact on human infrastructures in space and at Earth; therefore it is a great challenge developing robust methods that allow prediction of space weather events with sufficient accuracy. With the rapid increase in computational power, new opportunities are arising to address non-linear processes where numerical experiments can guide us to the frontiers of solar and space weather physics.

Acknowledgements

The authors would like to thank Ankit Agarwal, Philippe Azais, Jacob de Boer, Deniz Eroglu, Gérard Gebel, Didier Jamet, Juergen Kurths, Florence Lefebvre-Joud, Søren Linderoth, Alberto Loarte, Norbert Marwan, Natalio Mingo, Ugur Ozturk, Simon Perraud, Robert Pitz-Paal, Stefaan Poedts, Thierry Priem, Bernd Rech, Tuan Quoc Tran, Marco Ripani, Shubham Sharma, Hermann-Josef Wagner for their valuable contributions to the EPS Grand Challenges project.

▼ **FIG. 4:** One of the key drivers of space weather are solar eruptions. These include both solar flares and Coronal Mass Ejection

PHYSICS FOR SECURE AND EFFICIENT SOCIETIES

Christian Beck[1] **and Felicia Barbato**[2] – DOI: https://doi.org/10.1051/epn/2022506
[1] Queen Mary University and Alan Turing Institute, London, UK – [2] Gran Sasso Science Institute, Italy

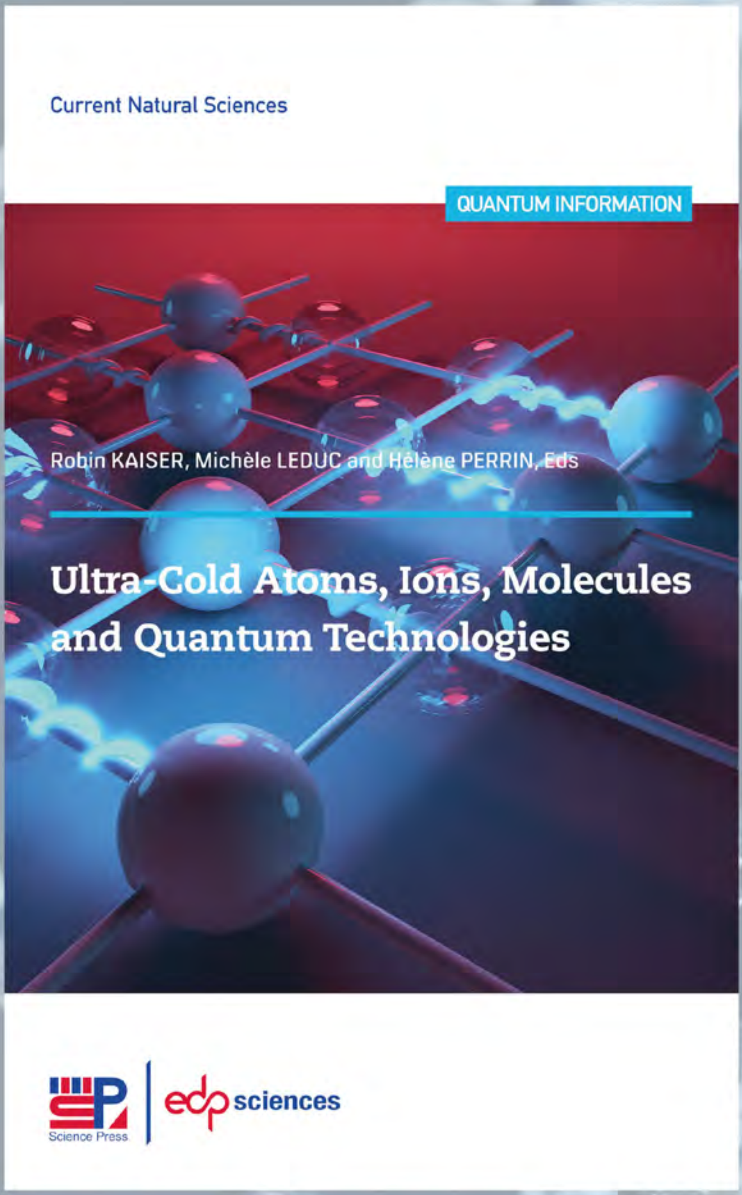
Physics research contains two very different aspects–there is the fundamental research driven by curiosity, with the ultimate aim of understanding very small interacting systems, very large interacting systems, and the complex behaviour on intermediate scales, but there is also the applied side, where physics is applied to develop new technologies, new analysis methods and new concepts and insights that are useful for society. Read about it in Chapter 6 of the EPS Grand Challenges for Physics.

▲FIG. 1: Augmented reality and smart sensors will allow greater control of production processes

Ultimately, much of what physics for interacting systems encounters with is nonlinear, high-dimensional, and complex, and the final goal is to apply novel physical insights to real-world systems, providing useful applications that are helpful for society in general. The topic of this chapter, physics for secure and efficient societies, is very broad and general, and has many different aspects, and our chapter in no way makes an attempt to treat it in full generality. Rather, we have selected a few topics that we find particularly interesting, with the emphasis of looking into the future—perhaps looking towards the year 2050 or towards a similar time scale.

Now available in English !

'Ultra-cold atoms, ions, molecules and quantum technologies'



Current Natural Sciences

QUANTUM INFORMATION

Robin KAISER, Michèle LEDUC and Hélène PERRIN, Eds

Ultra-Cold Atoms, Ions, Molecules and Quantum Technologies

Science Press | edp sciences

BY
Robin Kaiser,
Michèle Leduc,
Hélène Perrin

Also available in e-book format
For sale on laboutique.edpsciences.fr

ISBN : 978-2-7598-2745-9
192 illustrated pages
Price : 95 €
Available December 1, 2022

This book is the English translation of 'ATOMES, IONS, MOLÉCULES ULTRAFROIDS ET TECHNOLOGIES QUANTIQUES' that was awarded a **Special Prize** by the jury of the **'Prix Roberval 2022**' in the category 'Academic books'.

Prix Roberval

The field of cold atoms was born fourty years ago and today remains a theme regularly awarded Nobel Prizes and at the forefront of physics research. The book presents the most recent developments and traces the exceptional growth of this field over the last ten years.

Robin KAISER is Research Director at CNRS, Institut de physique de Nice, Université de la Côte d'Azur.
Michèle LEDUC is Research Director emeritus at CNRS, Laboratoire Kastler-Brossel, École Normale Supérieure, Paris.
Hélène PERRIN is Research Director at CNRS, Laboratoire de physique des lasers, Université Sorbonne Paris Nord.

> **Read more in Chapter 6 of the EPS Grand Challenges for Physics.**

Quantum computing. One important aspect for the future of society is the further development of information technologies—proper communication and information processing and enhanced computer development is absolutely essential. Our world today is dominated by computers in their various shapes and sizes, from small to big, from personal to institutional, from local to world-wide. Science has made immense progress by implementing modern machine learning technologies and artificial intelligence, so a natural question is where is computing going to, what is the next generation of computers made of, and what is the next generation of algorithms? Still in its infancy today, quantum computing may hold the key for outstanding novel computational developments of the future—some problems are so complex that they can't be solved with present conventional computers, but require something that is orders of magnitudes faster, or need algorithms and novel approaches that are very different from what is currently used in mainstream simulations.

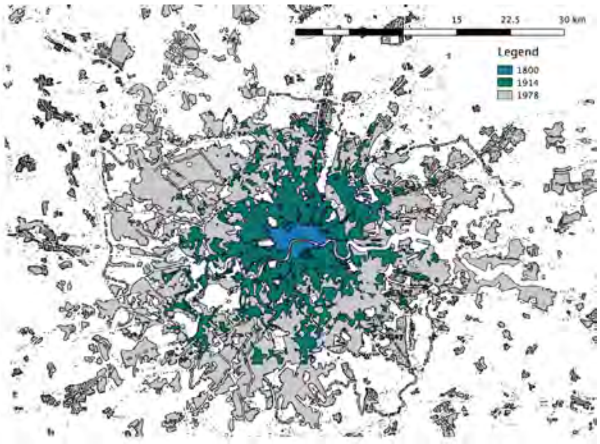
The article by Daniel Malz and J. Ignacio Cirac in our chapter summarises the most important principles of quantum computing, exploiting quantum superpositions and entanglement for the purpose of future quantum computers. The aim is to solve certain problems much faster than with conventional computers. In addition to this, the article by Zeki Can Seskir and Jacob Biamonte looks at the historical development of quantum computing research and in particular quantum algorithms and new types of machine learning models, which are expected to be very relevant in the future.

Sensor development. How do we actually get the data that we feed into our physical models, to make accurate predictions for the future, using the best computers and analytical techniques available? The problem is non-trivial, as bad data yield biased and unprecise predictions. Sensor technology has made immense progress recently. The convergence of multiple technologies, real-time analytics, machine learning, ubiquitous computing, embedded systems gave birth to the Internet of Things (IoT) and the automation and control of industrial processes can be seen as the fourth industrial revolution, also known as the Industrial Internet of Things (IIoT) [Figure 1]. In her article, Antigone Marino walks in the historical basic steps of sensor developments arriving then at the future challenges set by Europe climate change strategy for 2050. In this framework, smart sensors are fundamental for monitoring all services related to the automation of processes as regards to the sphere of waste reduction, clean water, environmental control and finally to expand the quality of life in the workplace.

Space exploration. The use of smart sensors is also open to the space sector which is gaining more and more importance and is going to enter in its golden age driven by the longstanding dream of mankind, the space exploration, with many interesting new perspectives and applications for the benefit of humans on the horizon. In his article on the space sector, Javier Ventura-Traveset reviews the current status of next future missions and explores the prospects of the space sector beyond 2030/2035. Many intriguing topics are covered, starting from more gnoseological problems like space science, going through futuristic scenarios about human and robotic exploration of space, and finally touching more practical issues like understanding the climate change trend, its sources, its dynamics and the major anthropogenic impacts. In this article, Javier Ventura-Traveset makes it very clear how space exploration has, and will have even more in the future, huge impact on our society both from the economical and the social point of view, and how future society can benefit from this emerging sector [Fig. 2].

▾ **FIG. 2:** The Galileo System constellation.

Complex systems. Finally, another problem of utmost relevance for future societies is the understanding of the complexity that is underlying the real-world systems that surround us and the daily life aspects of our living. Here statistical physics, in its modern form, has a lot to say.



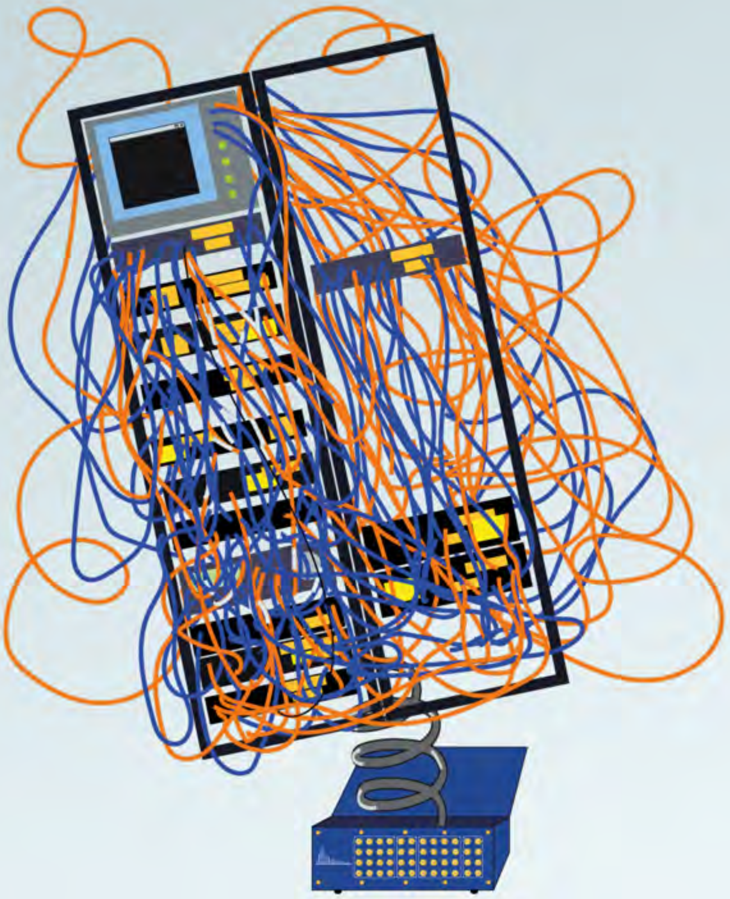
▲ **FIG. 3:** A city.

One particular example is the science of cities [Fig. 3]. A very large part of the world population these days live in cities, but how do cities actually function, how do they evolve, how can we improve the day-to-day structures and life quality in a sustainable and environmentally friendly way? Cities are spatially extended complex systems, and statistical physics, in its modern formulation, can be applied. In the historical Boltzmann formulation particles are replaced by agents (companies, vehicles, people, sustainable energy sources, …), interactions are replaced by communications (mobile phones, e-mail, Twitter, …), phase transitions correspond to an abrupt change of relevant observables (opinions, prices, behavioural patterns, …), and so on. In his article Marc Barthelemy provides a state-of-the-art overview on city modelling, city growth aspects, traffic congestion, and much more, using the tools of statistical physics and complex network theory.

Overall, the example topics treated in this chapter show that often there is initially fundamental basic physical science, which then feeds into more advanced applied models relevant for the future development. For example, starting from quantum physics we proceed to modern methods and algorithms of quantum computing, starting from classical equilibrium and nonequilbrium statistical physics we proceed to a modern science of cities, and so on. Better predictions and better models can be made if we have access to better data, obtained with more powerful sensors, by better satellite navigation methods, and so on. Let's hope that in 2050, most of the world's population will be living in a clean, peaceful and sustainable environment, where physics helped a lot to attain this stable state. ■

Acknowledgements

The authors would like to thank Marc Barthelemy, Jacob Biamonte, Ignacio Cirac, Daniel Malz, Antigone Marino and Javier Ventura-Traveset for their precious contributions to the Grand Challenges.



▲Talking birds as a symbol for open communication and education. ©iStockPhoto.

SCIENCE FOR SOCIETY

During the second part of the 20th century, the social contract between science and society was merely a tacit agreement foreseeing that public money would finance the research that would sustain technology development and innovation and enhance the socio-economic well-being of our society. The spheres of science, politics, and society were largely separate. Today this model has changed. Chapter 7 of the EPS Challenges for Physics deals with this issue.

Christophe Rossel[1] and Luc van Dyck[2] – DOI: https://doi.org/10.1051/epn/2022507

[1] IBM Research-Zurich, [2] Euro Argo ERIC, 29280 Plouzan?, France

In the last 25 years, this model has been broadly questioned. Blurred ethical standards and catastrophes in addition to the dissemination of “fake news” have repeatedly undermined the faith in science. Innovation has not always been driven by the Common Good or the needs and expectations of the citizens. Most importantly, there has been an increasing awareness that the world is facing new drastic challenges, from climate change and food security to migrations and energy supplies, which will determine its future.

Against this background, a new normal is arising. It is about the interplay of all sciences, including natural, social, and human sciences, without which societal challenges cannot be solved: education and training must be rethought to foster inter- and trans-disciplinarity. It is about a democratic governance of science and innovation which, while protecting the inspiration and creativity that drives research, facilitates the participation of all stakeholders in developing choices and processes. It is about greater expectations from citizens regarding communication and accountability from scientists at a time when the internet revolution and social media make it possible for all to access, understand and share the knowledge and scientific data. At the dawn of the open science era, it is also about reaping the benefits of Information Technology and Artificial Intelligence to consolidate and speed up the research and innovation process. Finally, it is about trust between citizens and science, which is conditioned by aspects of research such as ethics, integrity and transparency.

A global goal is to generate the new knowledge that will help to better understand and address the major challenges of our time and facilitate the transfer and integration of scientific findings into politics and society. But science has its own limits, being either theoretical, experimental, ethical or philosophical.

Since all these issues will determine the future of scientific research – and ipso facto of mankind – they are addressed and discussed in in a separate chapter of the EPS Grand Challenges. Chapter 7 of the EPS Grand Challenges is divided into five main sections: Education and research in an interdisciplinary environment, Science with and for the citizens, Open communication and responsible citizens, Science and ethics and finally the Limits of science. ■

> **“We need a new social contract between science and society”**

Acknowledgement

The authors would like to thank Alan Cayless, Tobias Beuchert, Jean-Claude Burgelmann, Frédéric Darbellay, Richard Dawid, Bengt Gustafsson, Philip Macnaghten, Eilish McLoughlin, Sally Jordan, Pedro Rodrigues Dos Santos Russo, Ernst Ulrich von Weizsäcker, François Weiss for their valuable contributions to the Grand Challenges.

Nobel Prize winning Physics

edp sciences

from the *Journal de Physique* digital archives

Researchers seek the highest quality physics regardless of where or when it was published. The *Journal de Physique* archives are full of the biggest names in physics including Curie, Planck, Rutherford, Becquerel and, more recently, Giorgio Parisi. This bi-lingual e-resource spans 1872-1997 – undoubtedly, one of the most exciting and influential periods in physics research.

- More than 300,000 pages in over 49,500 articles digitised to the highest quality
- Unique English and French content
- Available for outright purchase or as a subscription
- Fairly priced with flexible solutions

The *Journal de Physique* was created in 1872 by Charles d'Almeida “to invigorate teaching, to stimulate the spirit of research and provoke new discoveries”. Pioneering physicists Marie, Pierre and Irène Curie published several articles in the journal *Le Radium* and these remain preserved within the *Journal de Physique* archives.

Why are archives important?

- They provide historical context for current research
- They inspire researchers to explore new research ideas
- They broaden the resources available to library users
- They secure academic knowledge for future generations

“There is undoubtedly educational value to reading ‘legacy papers’, and this holds true for articles written in any language.”
Gaia Donati, *Discovery through multi-lingual science archives,* Research information

We believe that preserving legacy journal content and ensuring it remains discoverable for future generations is vital to the advancement of science. Visit *our archives* to read some original articles and modern commentaries.

“Nothing in life is to be feared, it is only to be understood.”

Marie Curie

Journal de Physique archives

For more information

Contact:
Anne Simoneau,
Director of Business Development
anne.simoneau@edpsciences.org

Browse: edpsciences.org/archives